

**WHAT IS CLAIMED IS:**

1. A method of correcting thermally-induced field deformations of a lithographically exposed substrate, comprising:

    exposing a pattern onto a plurality of fields of a substrate in accordance with pre-specified exposure information;

    measuring attributes of said fields to assess deformation of said fields induced by thermal effects of said exposing;

    determining corrective information based on said measured attributes; and

    adjusting said pre-specified exposure information, based on said corrective information, to compensate for the thermally-induced field deformations.

2. The method of Claim 1, wherein said exposure information includes at least one of exposure energy information, exposure time information, exposure field position information, exposure field sequencing information, and exposure field deformation information.

3. The method of Claim 2, wherein said adjusting said pre-specified exposure information includes adjusting said pre-specified exposure field position information based on position offset information determined by said corrective information.

4. The method of Claim 2, further including,  
    providing a model to predict thermally-induced field deformation information,  
and

    modifying said pre-specified exposure information, prior to exposing, based on said predicted thermally-induced deformation information.

5. The method of Claim 4, wherein said adjusting said pre-specified exposure information includes adjusting said modified pre-specified exposure information, after said

exposing, based on predictive offset information determined by said corrective information.

6. The method of Claim 4, wherein said predicted thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a global expansion model.

7. The method of Claim 6, wherein said predictive model is based on:

$$[dx]_p = \left[ \frac{x}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dx_{max} \right]; \text{ and}$$

$$[dy]_p = \left[ \frac{y}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dy_{max} \right]; \text{ where}$$

$dx_p$ : represents the predicted deformation along the x axis;

$dx_{max}$ : represents the predicted total deformation of the wafer substrate W in the x direction after the last target field has been exposed;

x: represents the x coordinate of a point on the wafer substrate W;

$r_w$ : represents the radius of the wafer substrate W;

$N_i$ : represents the current target field index number;

$N_{tot}$ : represents the total number of target fields;

$dy_p$ : represents the predicted deformation along the y axis;

$dy_{max}$ : represents the predicted total deformation of the wafer substrate W in the y direction after the last target field has been exposed; and

y: represents the y coordinate of a point on the wafer substrate W.

8. The method of Claim 7, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said predicted thermally-induced field deformation information.

9. The method of Claim 4, wherein said thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a time-decaying characteristic as energy is transported across said wafer.

10. The method of Claim 9, wherein said predictive model is based on:

$$dx_p = \sum_i T_i^x D_i^x; \text{ and}$$

$$dy_p = \sum_i T_i^y D_i^y; \text{ where}$$

$T_i = e^{-\frac{t-t_i}{\tau}}$  : represents thermal effects of exposing one of said target fields  $C_i$  which will decay in time as energy is transported across said substrate in either the x or y direction;

$\tau$ : represents the time sensitivity constant which depends on the thermal properties of the lithographic exposure components;

$D_i = ke^{-|r_i - \bar{r}|/\chi}$ : represents effects induced by a distance  $r_i$  between said exposed target field  $C_i$  and target field to be currently exposed in either the x or y direction;

$\chi$ : represents the spatial thermal properties of the lithographic exposure components;

$k$ : represents a proportionality constant which depends on thermal properties of the lithographic exposure components;

$dx_p$ : represents predicted deformation along the x axis; and

$dy_p$ : represents predicted deformation along the y axis.

11. The method of Claim 10, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said predicted thermally-induced field deformation information.

12. The method of Claim 2, further including:

measuring temperature variations on surface of said substrate prior to exposing, and

generating a deformation map based on said measured substrate temperature variations.

13. The method of Claim 12, further including modifying said pre-specified

exposure information, prior to exposing, based on said deformation map.

14. The method of Claim 13, wherein said temperature variation measurement includes thermographic imaging.

15. The method of Claim 12, wherein said deformation map is characterized by:

$$[dx]_p = \left[ c \frac{x_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right];$$
$$[dy]_p = \left[ c \frac{y_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \text{ where}$$

$dx_p$ : represents the predicted deformation along the x axis;

$x_i$ : represents the x coordinate of field i;

$c$ : represents a proportionality constant (thermal expansion coefficient);

$N_i$ : represents the number of fields taken into account in the summation;

$k$ : sums over the relevant fields, along the connection line between the wafer centre and field i;

$T_k$ : represents the measured temperature of field k;

$T_{nom}$ : represents the nominal temperature for which the machine is set up;

$y_i$ : represents the y coordinate of field i; and

$dy_p$ : represents the predicted deformation along the y axis.

16. The method of Claim 13, wherein said adjusting said pre-specified exposure information includes adjusting said modified pre-specified exposure information, after said exposing, based on deformation offset information determined by said corrective information.

17. A method of correcting thermally-induced field deformations of a lithographically exposed substrate, comprising:

providing a model to predict deformation of a plurality of fields of a substrate induced by thermal effects of exposing;

modifying exposure information used to configure the exposure of said fields of said substrate based on said predicted thermally-induced deformation information;

exposing a pattern onto said fields of said substrate in accordance with said modified exposure information;

measuring attributes of said fields to assess deformation of said fields induced by thermal effects of said exposing;

determining corrective information based on said measured attributes; and

adjusting said modified exposure information, based on said corrective information, to compensate for the thermally-induced field deformations.

18. The method of Claim 17, wherein said predicted thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a global expansion model.

19. The method of Claim 18, wherein said predictive model is based on:

$$[dx]_p = \left[ \frac{x}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dx_{max} \right]; \text{ and}$$

$$[dy]_p = \left[ \frac{y}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dy_{max} \right]; \text{ where}$$

$dx_p$ : represents the predicted deformation along the x axis;

$dx_{max}$ : represents the predicted total deformation of the wafer substrate W in the x direction after the last target field has been exposed;

x: represents the x coordinate of a point on the wafer substrate W;

$r_w$ : represents the radius of the wafer substrate W;

$N_i$ : represents the current target field index number;

$N_{tot}$ : represents the total number of target fields;

$dy_p$ : represents the predicted deformation along the y axis;

$dy_{max}$ : represents the predicted total deformation of the wafer substrate W in the y direction after the last target field has been exposed; and

y: represents the y coordinate of a point on the wafer substrate W.

20. The method of Claim 19, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said

predicted thermally-induced field deformation information.

21. The method of Claim 17, wherein said thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a time-decaying characteristic as energy is transported across said wafer.

22. The method of Claim 21, wherein said predictive model is based on:

$$dx_p = \sum_i T_i^x D_i^x; \text{ and}$$

$$dy_p = \sum_i T_i^y D_i^y; \text{ where}$$

$T_i = e^{-\frac{t-t_i}{\tau}}$ : represents thermal effects of exposing one of said target fields  $C_i$  which will decay in time as energy is transported across said substrate in either the x or y direction;

$\tau$ : represents the time sensitivity constant which depends on the thermal properties of the lithographic exposure components;

$D_i = ke^{-|r_i - \bar{r}|/\chi}$ : represents effects induced by a distance  $r_i$  between said exposed target field  $C_i$  and target field to be currently exposed in either the x or y direction;

$\chi$ : represents the spatial thermal properties of the lithographic exposure components;

$k$ : represents a proportionality constant which depends on thermal properties of the lithographic exposure components;

$dx_p$ : represents predicted deformation along the x axis; and

$dy_p$ : represents predicted deformation along the y axis.

23. The method of Claim 22, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said predicted thermally-induced field deformation information.

24. A method of correcting thermally-induced field deformations of a lithographically exposed substrate, comprising:

measuring temperature variations on surface of a substrate containing a plurality of fields to be exposed;

generating a deformation map based on said measured substrate temperature variations;

modifying exposure information used to configure the exposure of said fields of said substrate based on said deformation map;

exposing a pattern onto said fields in accordance with said modified exposure information;

measuring attributes of said fields to assess deformation of said fields induced by thermal effects of said exposing;

determining corrective information based on said measured attributes; and

adjusting said modified exposure information, based on said corrective information, to compensate for the thermally-induced field deformations.

25. The method of Claim 24, wherein said temperature variation measurement includes thermographic imaging.

26. The method of Claim 24, wherein said deformation map is characterized by:

$$\begin{aligned} [dx]_p &= \left[ c \frac{x_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \\ [dy]_p &= \left[ c \frac{y_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \text{ where} \end{aligned}$$

$dx_p$ : represents the predicted deformation along the x axis;

$x_i$ : represents the x coordinate of field i;

$c$ : represents a proportionality constant (thermal expansion coefficient);

$N_i$ : represents the number of fields taken into account in the summation;

$k$ : sums over the relevant fields, along the connection line between the wafer centre and field i;

$T_k$ : represents the measured temperature of field k;

$T_{nom}$ : represents the nominal temperature for which the machine is set up;

$y_i$ : represents the y coordinate of field i; and

$dy_p$ : represents the predicted deformation along the y axis.

27. The method of Claim 26, wherein said adjusting said pre-specified exposure information includes adjusting said modified pre-specified exposure information, after said exposing, based on deformation offset information determined by said corrective information.

28. A method of correcting thermally-induced field deformations of substrates exposed by a lithographic apparatus, said method comprising:

determining corrective information based on exposed target fields of at least one prior substrate;

applying said corrective information to exposure information; and

exposing target fields of subsequent substrates in accordance with said exposure information having applied corrective information.

29. The method of Claim 28, wherein said exposure information includes at least one of exposure energy information, exposure time information, exposure field position information, and exposure field sequencing information.

30. The method of Claim 28, wherein said determining corrective information includes exposing a pattern onto a plurality of said target fields of said at least one prior substrate and measuring attributes of said target fields of said at least one prior substrate to assess deformation induced by thermal effects of said exposing.

31. The method of Claim 30, wherein said determining corrective information includes deriving a thermal corrective model characterized by:

$$\Delta \bar{r} \approx \sum T_i D_i \quad ; \text{ where}$$

$$T_i = T_i(t, t_i, \bar{C}) \quad ; \text{ and}$$

$$D_i = D_i(\bar{r}, \bar{r}_i, \bar{G})$$

wherein  $T_i$  represents thermal effects of exposing a target field  $C_i$ ,  $t$  is a current time,  $t_i$  is time of exposing target field  $C_i$ , and  $\bar{C} = (c_1, c_2, \dots, c_n)$  represents a vector of



calibrated parameters that correspond to thermal properties of the lithographic exposure components with respect to time; and

wherein  $D_i$  represents effects induced by a distance between the exposed target field  $C_i$  and the target field to be currently exposed,  $\bar{r}$  is a point of a wafer substrate  $W$  currently being exposed,  $\bar{r}_i$  is a point on target field  $C_i$ , and  $\bar{G} = (g_1, g_2, \dots, g_m)$  represents a vector of calibrated parameters that corresponds to thermal properties of the lithographic exposure components with respect to distance.

32. The method of Claim 30, wherein said determining corrective information includes employing a predictive model characterized by:

$$[dx]_p = \left[ \frac{x}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dx_{max} \right]; \text{ and}$$

$$[dy]_p = \left[ \frac{y}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dy_{max} \right]; \text{ where}$$

$dx_p$ : represents the predicted deformation along the x axis;

$dx_{max}$ : represents the predicted total deformation of the wafer substrate  $W$  in the x direction after the last target field has been exposed;

$x$ : represents the x coordinate of a point on the wafer substrate  $W$ ;

$r_w$ : represents the radius of the wafer substrate  $W$ ;

$N_i$ : represents the current target field index number;

$N_{tot}$ : represents the total number of target fields;

$dy_p$ : represents the predicted deformation along the y axis;

$dy_{max}$ : represents the predicted total deformation of the wafer substrate  $W$  in the y direction after the last target field has been exposed; and

$y$ : represents the y coordinate of a point on the wafer substrate  $W$ .

33. The method of Claim 30, wherein said determining corrective information includes employing a predictive model characterized by:

$$dx_p = \sum_i T_i^x D_i^x; \text{ and}$$

$$dy_p = \sum_i T_i^y D_i^y; \text{ where}$$

$T_i = e^{-\frac{t-t_i}{\tau}}$  : represents thermal effects of exposing one of said target fields  $C_i$  which will decay in time as energy is transported across said substrate in either the x or y direction;

$\tau$ : represents the time sensitivity constant which depends on the thermal properties of the lithographic exposure components;

$D_i = ke^{-|\bar{r}_i - \bar{r}|/\chi}$ : represents effects induced by a distance  $r_i$  between said exposed target field  $C_i$  and target field to be currently exposed in either the x or y direction;

$\chi$ : represents the spatial thermal properties of the lithographic exposure components;

$k$ : represents a proportionality constant which depends on thermal properties of the lithographic exposure components;

$dx_p$ : represents predicted deformation along the x axis; and

$dy_p$ : represents predicted deformation along the y axis.

34. The method of Claim 30, wherein said determining corrective information comprises:

measuring temperature variations on surface of said at least one prior substrate, and

generating a deformation map based on said measured substrate temperature variations,

wherein said deformation map is characterized by:

$$\begin{aligned} [dx]_p &= \left[ c \frac{x_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \\ [dy]_p &= \left[ c \frac{y_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \text{ where} \end{aligned}$$

$dx_p$ : represents the predicted deformation along the x axis;

$x_i$ : represents the x coordinate of field  $i$ ;

$c$ : represents a proportionality constant (thermal expansion coefficient);

$N_i$ : represents the number of fields taken into account in the summation;

$k$ : sums over the relevant fields, along the connection line between the wafer centre and field  $i$ ;

$T_k$ : represents the measured temperature of field  $k$ ;

$T_{nom}$ : represents the nominal temperature for which the machine is set up;

$y_i$ : represents the  $y$  coordinate of field  $i$ ; and

$dy_p$ : represents the predicted deformation along the  $y$  axis.

35. A lithographic system, comprising:

an illumination system configured to provide a beam of radiation;

a support structure configured to support a patterning device that serves to impart said beam of radiation with a pattern in its cross-section;

a substrate holder configured to hold a substrate containing a plurality of target fields;

a projection system configured to expose said patterned beam onto at least one of said target fields of the substrate; and

a measurement station configured to measure attributes of said exposed target fields,

wherein said exposed target fields are exposed in accordance with pre-specified exposure information, said fields are measured by said measurement station to assess deformation of said fields induced by thermal effects of said exposing, and

wherein corrective information is determined based on said measured field deformations and said pre-specified exposure information is adjusted, based on said corrective information, to compensate for the thermally-induced field deformations.

36. The lithographic system of Claim 35, wherein said exposure information includes at least one of exposure energy information, exposure time information, exposure field position information, exposure field sequencing information, and exposure field deformation information.

37. The lithographic system of Claim 36, wherein said adjusting said pre-specified exposure information includes adjusting said pre-specified exposure field position information based on position offset information determined by said corrective information.

38. The lithographic system of Claim 36, further including,  
providing a model to predict thermally-induced field deformation information,  
and  
modifying said pre-specified exposure information, prior to exposing, based on  
said predicted thermally-induced deformation information.

39. The lithographic system of Claim 38, wherein said adjusting said pre-specified exposure information includes adjusting said modified pre-specified exposure information, after said exposing, based on predictive offset information determined by said corrective information.

40. The lithographic system of Claim 38, wherein said predicted thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a global expansion model.

41. The lithographic system of Claim 40, wherein said predictive model is based on:

$$[dx]_p = \left[ \frac{x}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dx_{max} \right]; \text{ and}$$

$$[dy]_p = \left[ \frac{y}{r_w} \cdot \frac{N_i}{N_{tot}} \cdot dy_{max} \right]; \text{ where}$$

$dx_p$ : represents the predicted deformation along the x axis;

$dx_{max}$ : represents the predicted total deformation of the wafer substrate W in the x direction after the last target field has been exposed;

x: represents the x coordinate of a point on the wafer substrate W;

$r_w$ : represents the radius of the wafer substrate W;

$N_i$ : represents the current target field index number;

$N_{tot}$ : represents the total number of target fields;

$dy_p$ : represents the predicted deformation along the y axis;

$dy_{max}$ : represents the predicted total deformation of the wafer substrate W

in the y direction after the last target field has been exposed; and  
y: represents the y coordinate of a point on the wafer substrate W.

42. The lithographic system of Claim 41, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said predicted thermally-induced field deformation information.

43. The lithographic system of Claim 38, wherein said thermally-induced field deformation information includes predicting deformation effects of selected points within each of said fields based on a time-decaying characteristic as energy is transported across said wafer.

44. The lithographic system of Claim 43, wherein said predictive model is based on:

$$dx_p = \sum_i T_i^x D_i^x; \text{ and}$$

$$dy_p = \sum_i T_i^y D_i^y; \text{ where}$$

$T_i = e^{-\frac{t-t_i}{\tau}}$  : represents thermal effects of exposing one of said target fields  $C_i$  which will decay in time as energy is transported across said substrate in either the x or y direction;

$\tau$ : represents the time sensitivity constant which depends on the thermal properties of the lithographic exposure components;

$D_i = ke^{-|r_i - \bar{r}|/\chi}$ : represents effects induced by a distance  $r_i$  between said exposed target field  $C_i$  and target field to be currently exposed in either the x or y direction;

$\chi$ : represents the spatial thermal properties of the lithographic exposure components;

$k$ : represents a proportionality constant which depends on thermal properties of the lithographic exposure components;

$dx_p$ : represents predicted deformation along the x axis; and

$dy_p$ : represents predicted deformation along the y axis.

45. The lithographic system of Claim 44, wherein said adjusting said pre-specified exposure information includes adjusting said exposure field sequencing information based on said predicted thermally-induced field deformation information.

46. The lithographic system of Claim 36, further including:  
measuring temperature variations on surface of said substrate prior to exposing, and  
generating a deformation map based on said measured substrate temperature variations.

47. The lithographic system of Claim 46, further including modifying said pre-specified exposure information, prior to exposing, based on said deformation map.

48. The lithographic system of Claim 46, wherein said temperature variation measurement includes thermographic imaging.

49. The lithographic system of Claim 46, wherein said deformation map is characterized by:

$$\begin{aligned} [dx]_p &= \left[ c \frac{x_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \\ [dy]_p &= \left[ c \frac{y_i}{r_w} \frac{1}{N_i} \sum_k (T_k - T_{nom}) \right]; \text{ where} \end{aligned}$$

$dx_p$ : represents the predicted deformation along the x axis;

$x_i$ : represents the x coordinate of field i;

$c$ : represents a proportionality constant (thermal expansion coefficient);

$N_i$ : represents the number of fields taken into account in the summation;

$k$ : sums over the relevant fields, along the connection line between the wafer centre and field i;

$T_k$ : represents the measured temperature of field k;

$T_{nom}$ : represents the nominal temperature for which the machine is set up;

$y_i$ : represents the y coordinate of field i; and

$dy_p$ : represents the predicted deformation along the y axis.

50. The lithographic system of Claim 47, wherein said adjusting said pre-specified exposure information includes adjusting said modified pre-specified exposure information, after said exposing, based on deformation offset information determined by said corrective information.